

THE CIRCUMSTELLAR DUST OF “BORN-AGAIN” STARS

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Abstract. We describe the evolution of the carbon dust shells around Very Late Thermal Pulse (VLTP) objects as seen at infrared wavelengths. This includes a 20-year overview of the evolution of the dust around Sakurai’s object (to which Olivier made a seminal contribution) and FG Sge. VLTPs may occur during the endpoint of as many as 25% of solar mass stars, and may therefore provide a glimpse of the possible fate of the Sun.

1 Introduction

It is well-known that the fate of a star after it has evolved away from the Main Sequence (MS) depends on its mass. The accepted scenario for the post-MS evolution of low to intermediate mass stars is that, following the helium flash, burnout of He occurs in the core on the horizontal branch. After evolution up the Asymptotic Giant Branch, the star sheds its outer envelope, which is illuminated as a planetary nebula (PN) by the still-hot stellar core.

However, in as many as 20% of cases (Blöcker 2001) the star, as it evolves towards the white dwarf (WD) region of the HR diagram, re-ignites a residual helium shell in a VLTP and retraces its evolutionary track to the right to become a born again red giant (BAG; see Herwig 2005 and references therein). The final evolution to a WD is predicted to take roughly a few centuries, thus representing a very rapid (and hence seldom seen) phase of stellar evolution. A very small number of stars is known to have undergone VLTPs, e.g. Sakurai’s Object (V4334 Sgr), V605 Aql and FG Sge. All are C-rich, H-poor, have extensive dust shells, and lie at the centre of a PN. Observations of BAGs in the past ~ 20 years have shown that the rate at which the final evolution occurs has been seriously *underestimated*.

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2 Observations

We have a long-standing programme of observations of BAGs at infrared (IR) wavelengths, some extending at least over a couple of decades. These included ground-based observations (e.g. Woodward *et al.*, 1993; Tyne *et al.*, 2002; Gehrz *et al.*, 2005) and observations using the *Spitzer Space Telescope* Infrared Spectrograph (e.g. Evans *et al.* 2006) and the FORCAST grism spectrometer on the Stratospheric Observatory for Infrared Astronomy (*SOFIA*).

2.1 FG Sge

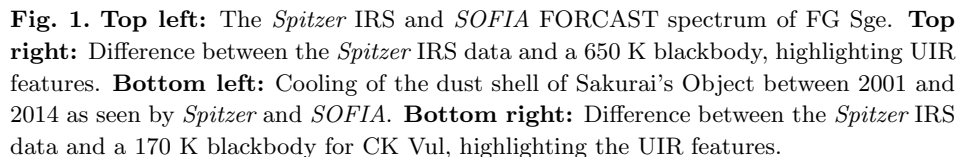
FG Sge underwent its VLTP in 1880. The 5–36 μm spectrum as observed by *Spitzer* and *SOFIA* is shown in Fig. 1. There is clearly a dust continuum, at a temperature ~ 650 K. This is considerably lower than that determined by either Woodward *et al.* (1993) or Gehrz *et al.* (2005), who found that there was a major dust-formation event sometime between 1983 and 1992. They also found that, over the period 1992–2001, the dust temperature was consistently within ± 200 K of 1000 K, indicating that mass-loss and dust production was continuing.

More recent *Spitzer* data show that, sometime between 1992 and 2006 (the date of the first *Spitzer* observation) mass loss had ceased and that the dust shell had started cooling. Of interest is the difference between the underlying 650 K blackbody and the *Spitzer* IRS spectrum, shown in Fig. 1. There is clear evidence for hydrocarbon “Unidentified InfraRed” (UIR) emission, and absorption by acetylene (C_2H_2 ; 13.688 μm); this demonstrates that the mass lost in the 1992–2001 episode (Gehrz *et al.*, 2005) was carbon-rich. Also highlighted are two weak emission features at 33.45 μm and 34.75 μm (see below). The *SOFIA* FORCAST observation, obtained in 2014, show that the dust has further cooled (see Fig. 1).

2.2 Sakurai’s Object

The VLTP of Sakurai’s Object occurred in 1996. Thorough analyses of the IR development and the implications for the evolution of the (carbon) dust produced are given by Tyne *et al.* (2002) and Hinkle & Joyce (2014). This object also showed C_2H_2 in absorption, as well as HCN and a range of polyynes (HC_nN ; Evans *et al.* 2006). The ejection of an optically thick carbon dust shell commenced in late 1997 (Evans *et al.* 2006; Hinkle & Joyce 2014); following the dust ejection event the central star has been completely ($V \gtrsim 24$) obscured, and has only recently (2015 February) become visible at $V \simeq 17$. Exquisite observations by Chesneau *et al.* (2009) with the mid-IR interferometer MIDI/VLTI showed that the dust was confined to a disc.

The cooling of the dust shell from 620 K to 180 K, as observed from the ground (UKIRT+JCMT) and from space- and air-borne (*Spitzer*, *SOFIA*) observations, is shown in Fig. 1. The HCN isotopologues in the *Spitzer* IRS spectra show that the $^{12}\text{C}/^{13}\text{C}$ ratio is $\simeq 3.2$, consistent with that deduced from the fundamental and first overtone CO absorption (Eyres *et al.*, 2004; Pavlenko *et al.*, 2004), and with its VLTP status.



The nature of CK Vul is unclear. Once thought to be the oldest “old nova” (Shara *et al.*, 1985) – it erupted in 1670 – it has also been suggested that it is a BAG (Evans *et al.*, 2006 and references therein), a diffusion-induced nova (Miller Bertolami *et al.*, 2011), and a stellar merger (Kaminski *et al.*, 2015).

We also note the two features at $33.45\ \mu\text{m}$ and $34.75\ \mu\text{m}$, also present in FG Sge (see above). They are labelled as being due to [S III] and [Si II] in Fig. 1 but they are extraordinarily strong in CK Vul compared to their strength in FG Sge. There seems to be no reasonable way in the case of CK Vul to account for these features in terms of ionic emission only. It may be that they arise either in entirely different

environments in the two objects, or in different carriers.

3 Conclusion

Observations of the BAG phenomenon at mid-to-far IR ($5\text{--}38\,\mu\text{m}$) wavelengths provide a wealth of information (e.g. about the mineralogy of the dust, far IR fine structure lines) – and hence about the circumstellar environment of BAGs – that can be obtained by no other means. Observations of BAGs using *SOFIA* are continuing and will be reported elsewhere.

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